

99A

HANDBOOK FOR
MUTUAL AND SELF INDUCTANCE BRIDGE

Handbook No. 163

Issue 6

TYPE 1852

MP MASTER



MA23842

Rank Lintel

CINEMA-TELEVISION LIMITED
Worsley Bridge Road,
Lower Sydenham,
LONDON, S.E.26.

Telephone:
Hither Green 4600

JANUARY, 1954.

HANDBOOK FOR
MUTUAL AND SELF INDUCTANCE BRIDGE

Contents

	<u>Page</u>
<u>GENERAL</u>	1
<u>PRINCIPLE</u>	1
<u>CIRCUIT DESCRIPTION</u>	2
Power Supplies	2
Oscillator	3
Detector Amplifier	4
Reference Signal Circuit	4
Phase-Sensitive Detector	5
Ranges	5
<u>MISCELLANEOUS</u>	6
Valves Used	6
Power Consumption	6
Dimensions	6
<u>OPERATING INSTRUCTIONS</u>	
To measure self inductance or resistance	6
To Measure mutual inductance	8
<u>SETTING-UP</u>	8
General	8
Meter Zero	8
Dial Zeros	8
Detector Phase Adjustment VR3	9
Slidewire Range Control VR2	9
Trimming Capacitors	10

MUTUAL AND SELF INDUCTANCE BRIDGEGENERAL

This audio-frequency bridge is designed for the accurate measurement of low mutual or self inductance in the range 0.001 microhenry to 30 millihenries. Provision is also made for the measurement of series resistance. The instrument enables rapid and accurate measurements to be made on coils having a low "Q" value at audio frequencies, such as the tuning coils used in radio and television receivers. It may also be applied in the measurement of correcting inductances, leading coils, transmission line impedances and circuit "strays." This latter application is particularly useful in the testing of high frequency circuits.

The bridge is conveniently used for the setting-up of artificial transmission lines, each section being treated as a three terminal network. Mutual resistance can also be measured and the bridge may be used for the measurement of low resistance values, the lowest calibrated value being 100 microhms.

PRINCIPLE

The principle upon which the bridge operates is illustrated in Figure 1. A high-impedance generator G supplies a circuit comprising an unknown impedance Z_x connected in series with an adjustable negative impedance $-Z$. If the value of $-Z$ be made equal to the impedance of Z_x , the circuit will have zero impedance and the detector D will show a null reading.

This basic circuit is inconvenient for certain reasons and it is advantageous to make connection to the unknown impedance by way of transformers, which may be of unity ratio, as shown in Figure 2. With this arrangement the range of measurement cannot exceed the range of adjustment of the balance component $-Z$. To extend the range, the ratios of both transformers may be changed from unity, as illustrated in Figure 3. The impedance Z_x of the unknown is then related to the magnitude of the variable impedance $-Z$ at balance, which may be written as Z_b , by the equation

$$Z_x = n.m.Z_b$$

where $l:m$ is the turns ratio of the current transformer interposed between the generator and the unknown impedance and $n:1$ is the ratio of the voltage transformer interposed between the unknown impedance and the detector.

In practice the adjustable balancing impedance has separately-variable inductive and resistance components, and the detector may be made sensitive only to the resistive or to the inductive component of the voltage applied to it from the bridge, so that the two balances are only slightly interdependent.

Figure 4 illustrates the basic circuit of the actual instrument, the circuit references being the same as those used in the complete circuit diagram.

Current from the output transformer T3 of the generator is fed to the primary winding of a current transformer T4, which has connected in series with it the primary winding of the mutual inductor MI.1 and the slide wire SL1 and resistor R28. Current induced in the secondary winding of T4 flows through the unknown impedance Z_x .

The voltage drop across Z_x is applied to the primary of a potential transformer T6, whose secondary is connected in series with the secondary winding of mutual inductor MI.1, the secondary of transformer T5 and resistor R28.

The sense in which the secondary windings of mutual inductor MI.1 and transformer T5 are connected to the secondary of T6 is such that the inductive and resistive components of voltage are induced in the secondary circuit in opposition to those from T6, i.e. the transferred impedances appear as negative. Thus potentials transferred to the secondary winding of T6 are balanced against those derived from MI.1 and SL1 (via T5), which are adjusted until detector D indicates their equality by a null reading.

A phase-sensitive detector is employed, which can be switched to respond only to the resistive or to the inductive component of voltage applied to it. This arrangement renders the resistance and inductance balances substantially independent of each other.

The resistance of R28 appears in the secondary circuit as a negative mutual resistance and is provided to ensure that the zero of the resistance scale is not at the end of the slide wire. This arrangement avoids the difficulty of reaching a true zero point because of wiring resistance external to the slide wire itself.

CIRCUIT DESCRIPTION (Drawing No. 31E/1949)

Power Supplies

The power supplies for the instrument are obtained from the alternating current mains. The supply is controlled by a double pole ON/OFF switch S1 and fuses F1, F2 and then applied to the primary of transformer T1. This winding is tapped to accept supplies of 100-110 and 200-250 volts; at 40-60c/s.

The H.T. supply to the valves is obtained by means of a full-wave rectifier V1 and smoothed by a conventional condenser-input filter L1, C1, and C2. An under-run pilot lamp PL1 is connected in series with a resistor across the heater supply to indicate when the instrument is switched on.

Oscillator

The oscillator comprises a Hartley circuit employing a centre-tapped tuning inductor LC1, tuned by C6 and C7 to a frequency of 1592c/s. This frequency is chosen as it corresponds to an angular frequency of 10,000 radians/second which is convenient for reactance calculations.

The grid of the oscillator valve V3A has its positive excursion limited by diode V2, whose cathode is connected to a point of suitable potential. Thus the drive applied from the tuned circuit via C8 to the grid of V3A cannot exceed that necessary to maintain the desired amplitude of oscillation.

The signal from the anode of V3A is fed via C9 and R9 to the grid of V3B. This valve has included in its anode circuit the primary winding of the bridge input transformer T3 and in its cathode circuit a resistor R8, which provides negative current feedback to maintain a substantially constant current in the primary winding of T3 irrespective of the load imposed by the impedance being measured. The high impedance source thus provided has the advantage that the bridge sensitivity becomes much less dependent on the value of the impedance being measured.

Bridge

The ratio of transformer T4 whose secondary feeds current through the unknown impedance via terminals A1-A2, is varied according to the range of measurement required by means of two banks S2/1 and S2/3 of the range switch S2. S2/1 alters the secondary connections to the unknown for each decade range, while S2/3 connects the input from T3 to either the whole or to one third of the primary winding of T4 to provide the "x3" ranges interpolated between the "x10" ranges.

Connected across the source in series with the primary of T4 are the primary winding of the mutual inductor MI.1, the slide wire SL1 and resistor R28; the voltage appearing across the tapped portion of SL1 is applied to the primary of transformer T5, whose secondary winding is connected in series with the secondary winding of MI.1, giving the effect of negative resistance as already explained.

The effective value of resistance required to accord with the mutual inductor employed is 122. This is an inconvenient value, as it is too low for a normal potentiometer type component and too high for a slide wire of normal construction. This difficulty is overcome by the use of a two-ohm slide wire in conjunction with transformer T5, which is given a step-up ratio of 6.3:1 and therefore transfers the voltage drop across this resistor to the

secondary circuit, so that it appears equivalent to the drop across a 12 Ω resistor.

VR2 in shunt with the slide wire enables it to be adjusted to the required effective resistance of 2 Ω so that the scale calibration is correct.

Resistor R28 is common to both primary and secondary circuits and the connections of transformer T6 are such that it appears as a negative mutual resistance whose purpose has already been explained.

Voltages appearing across the unknown impedance by reason of the current fed through it are applied through terminals B1-B2 to the primary winding of potential transformer T6 via range switch S2/2. The primary winding is shunted by one of the trimming capacitors C16-C23 (selected by S2/4) which are provided to compensate for the variation in effective leakage reactance in T6.

Detector Amplifier

The resultant signal appearing across the secondary of transformer T6, the secondary of M1.1 and the mutual resistance components in series is applied to the primary winding of the bridge output transformer T8, which has a step-up ratio of 70:1. The signal from the secondary of T8 is amplified by a three-stage R-C coupled amplifier comprising V7, V8A and V8B. The response of this amplifier is arranged to fall off rapidly on either side of the oscillator frequency to prevent trouble from hum pickup or response to harmonics of the oscillator. The signal appearing across the anode load resistors R35 and R36 is applied via the Key switch to the Phase Sensitive Detector. The purpose of the two different anode load resistors is to achieve approximately equal sensitivity on resistance and inductance balance.

Reference Signal Circuit

An output is taken from the oscillator via R12 to the grid of the cathode follower V4A. The signal appearing across the cathode load R15 of this valve is applied to the primary winding of the transformer T7, which has in its secondary circuit a phase-shifting network.

This network is adjusted to provide signals differing in phase by 90 $^{\circ}$ and the circuit parameters are so chosen that operation of S3 applies to transformer T2, via cathode follower V4B, a voltage either in phase with the voltage derived from the bridge amplifier when a pure resistance is being measured or 90 $^{\circ}$ lagging with respect to this voltage. Adjustment of VR3 (Detector Phase) adjusts the phase of both these voltages simultaneously without altering the 90 $^{\circ}$ difference between them.

Phase-Sensitive Detector

The balanced secondary winding of transformer T2 feeds the anode of double diode V5 with a voltage which is either in phase with the resistive component of the signals voltage applied to the detector from the bridge amplifier or 90° lagging with respect to this component. To the centre-tap of the secondary winding of T2 is applied the output from the detector amplifier, which is thus added to the voltages induced in each half of the secondary winding and applied to the anodes of the diode.

Any component in the output of the bridge amplifier which is in phase with the voltage applied from T2 to one diode will be 180° out-of-phase with the voltage applied to the other diode, hence it will produce an out-of-balance condition in the voltages appearing across diode loads R18 and R19. On the other hand, any voltage component which is 90° out-of-phase with the voltages in T2 will affect both diodes equally and will not produce an out-of-balance component. Thus only that component of output voltages from the bridge amplifier which is in phase with the voltage selected by S3 will affect the balance meter.

The d.c. voltages appearing across the load resistors R18, R19 of the double diode V5 are applied to the grids of the double triode V6. Between the cathodes of this valve is connected the centre-zero balance indicating meter M1. This indicates zero when the cathode potentials are equal, that is, when the applied grid voltages are equal. The direction of meter deflexion on unbalance is arranged to indicate the direction of movement of the balance control required to obtain balance, a left hand deflexion of the meter requires a clockwise rotation of the balance control to restore it to zero and vice-versa.

It is arranged that the maximum unbalance in the voltages applied to the grids of V6 cannot exceed that required for maximum deflexion of the balance meter, so that overloading of the meter is impossible. The potentiometer VR1 is employed to set the meter to zero in the absence of a signal from the bridge. Resistor R24 which is common to the cathode circuits of both triodes provides degeneration of any unbalanced signals appearing between both grids of V6 and earth, leaving the wanted balanced signals unaffected.

Ranges

The calibrated range of mutual and self inductance extends from 0.001 microhenry to 30 millihenries and the resistance range from 100 microhms to 3,000 ohms. Full accuracy is obtained upwards from 0.03 microhenry and 3 milliohms respectively. Both ranges are covered in twelve steps, the maximum reading on each step being greater than that on the step below by alternate multiples of 3 and 10 so that it is never necessary to use the lower and less accurate portion of the scale to obtain a

balance. On the lowest four ranges the full accuracy may not be obtained when measuring an inductance of very low "Q", i.e. a truly non-inductive resistor may show some reactive component, but the resistance will be accurately measured.

The accuracy of the measurement is $\pm 1\%$ of the full-scale reading on all ranges. The actual ranges obtained for each of the twelve settings of the range switch are as follows:-

<u>Inductance</u> <u>(Full scale)</u>	<u>Resistance</u> <u>(Full scale)</u>
0.1 μ H	.01 Ω
0.3 μ H	.03 Ω
1.0 μ H	.1 Ω
3.0 μ H	.3 Ω
10 μ H	1 Ω
30 μ H	3 Ω
0.1mH	10 Ω
0.3mH	30 Ω
1.0mH	100 Ω
3.0mH	300 Ω
10mH	1000 Ω
30mH	3000 Ω

MISCELLANEOUS

Valves Used

- 1 Mullard EZ35
- 2 Mullard EB34
- 2 Mullard ECC35
- 1 Mullard EF37
- 2 Brimar 6SN7GT

Power Consumption

50 Watts (approximately)

Dimensions

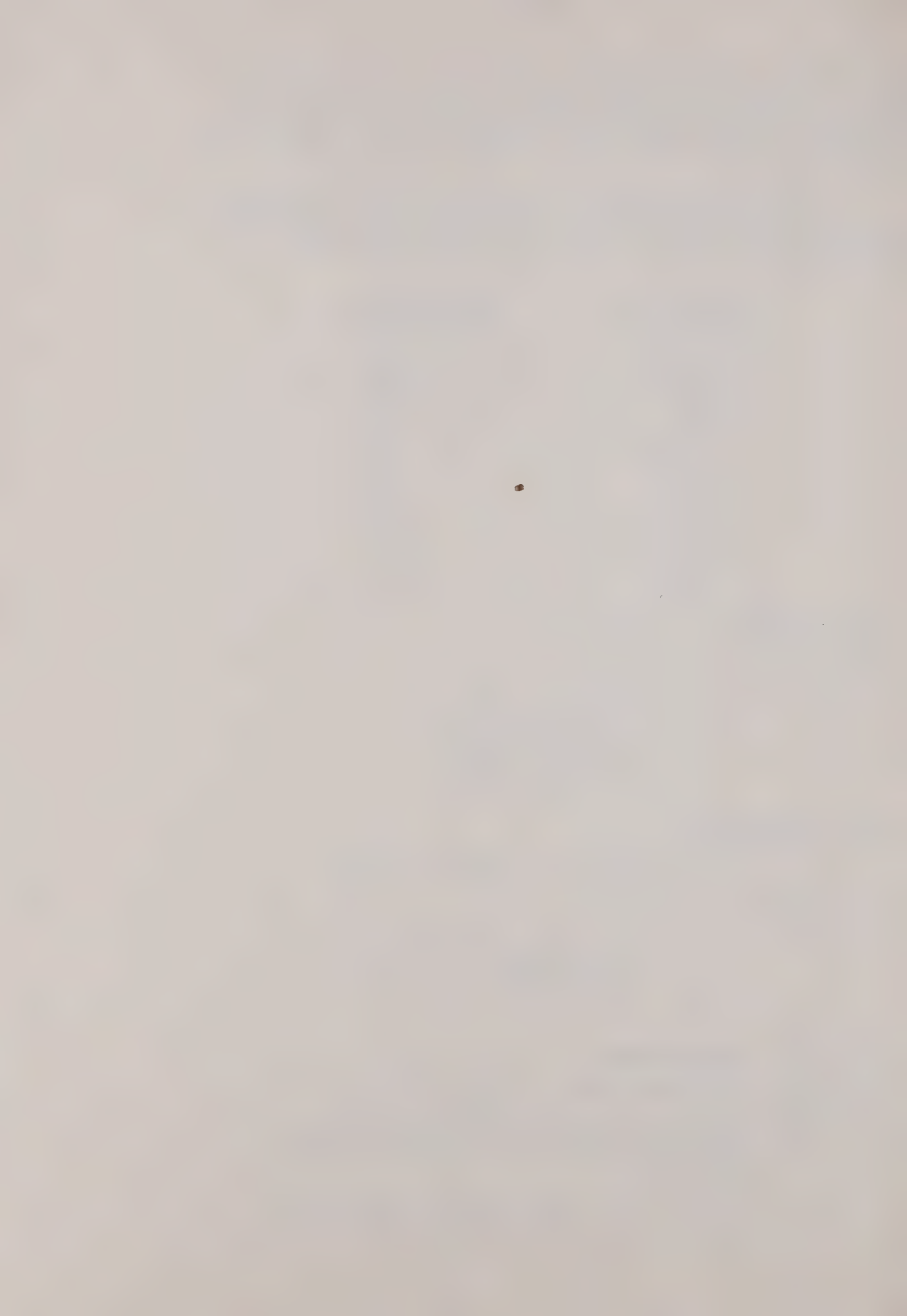
18 inches x 13 inches x
10 $\frac{1}{2}$ inches
45.6 cms x 33.0 cms x
26.7 cms.

OPERATING INSTRUCTIONS

To Measure Self Inductance or Resistance

- (1) Connect the coil to be measured to the four terminals as shown in Figure 5 or Figure 6.

Note that the four-terminal method of measurement employed enables the resistance

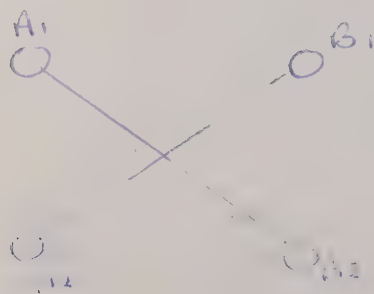


and inductance of the connecting leads to be ignored, provided that they are not excessively long.

When a very low resistance, such as a short length of resistance wire, is to be measured the leads should be connected as shown in Figure 6 thus avoiding inaccuracies due to lead or contact resistance. The resistance actually measured is the resistance between the connections of the potential leads from the B terminals, as indicated at "R". If long leads are required to connect the unknown to the bridge, these should be twisted in pairs, A1 with A2 and B1 with B2. The A1 and B1 leads must be taken to the same terminals of the unknown or the impedance will appear as negative.

- (2) Set the RANGE SWITCH to 30mH.
- (3) Operate the Key Switch to the left, that is to BALANCE RESISTANCE.
- (4) Balance meter reading to zero by adjustment of the RESISTANCE dial, turning the control in the direction in which the meter needle must move to the zero point.
- (5) Operate the Key Switch to the right, that is to BALANCE INDUCTANCE.
- (6) Balance meter reading to zero by adjustment of the INDUCTANCE dial.
- (7) Repeat operations (3) to (6). If the inductance being measured is greater than 30mH it is beyond the range of the bridge and balance cannot be obtained. If it is less than 30mH and more than 10mH, an accurate balance may be made on this range. If, however, the value is less than, say 3mH, the setting of the Inductance dial will be near zero and the highest accuracy will not be attained. To find the correct range, turn RANGE switch two or three steps anti-clockwise and re-balance (operations (3) to (6)). If the point of balance is still near zero, rotate the range switch still further until a range is found at which a satisfactory balance can be found.

This full procedure is necessary only when it is impossible to guess the approximate value of the inductor. It is generally possible to distinguish whether a component will have an inductance in the millihenry or microhenry range by its appearance, and a start may be made with the range switch in a more appropriate position. If any difficulty is found the full procedure given above will always give the correct result.



(a) ... (b) ... 11-01-12-15

(c) ... Zero Test.

It is advised that the operator spend a few minutes practising with various values of inductance. In this way he will "get to know" the bridge and will find balancing a very simple operation.

To Measure Mutual Inductance

- (1) Connect the coils to the four terminals as shown in Figure 7.
- (2) Balance bridge exactly as for a self-inductance (operations (2) to (7) above). Note that it is possible to obtain a NEGATIVE mutual inductance. If a balance is obtained on a negative dial reading reverse the connecting leads to ONE ONLY of the coils. In this case the RESISTANCE dial indicates Mutual Resistance, which will in most cases be zero.

SETTING-UP

General

Certain preset controls are provided in the instrument. They are adjusted before the instrument is despatched from the factory and should not be disturbed unless it becomes evident that the instrument is not operating correctly.

Meter Zero (VR1)

This control is placed on the front panel of the instrument for easy access, this is the ADJUST METER ZERO Control, operating resistor VR1, which is set to obtain zero reading on the balance meter when there is no output from the bridge circuit.

To adjust this control, put the Key switch into the central SET ZERO position thus removing any input signal to the detector, and turn the control by means of a screwdriver to the position giving zero meter deflexion.

If it is suspected that the meter zero has shifted, it is well to examine the instrument when switched off, to determine that the meter then reads zero. Any error at this time should be adjusted by the mechanical control on the meter itself.

Dial Zeros

The RESISTANCE and INDUCTANCE dials should read zero when terminals A1-B1 and A2-B2 are strapped with short pieces of heavy-gauge wire. If a zero error is found, this may be due to slipping of the dial on its shaft. The clamping screw should be loosened and the dial adjusted to read zero when the bridge is balanced on a high range.

When the zero of the INDUCTANCE dial has thus been set on a high range, it may be found that it does not hold on lower ranges. This may be corrected by bending the stiff wires connected to the A and B terminals behind the front panel.

Detector Phase Adjustment VR3.

The function of this control is to enable the phase angles of the reference voltages to be adjusted so that the Resistance and Inductance balances are substantially independent of each other.

Should it be found that the two balances are difficult to obtain because of interaction, the following procedure may be adopted for obtaining the correct conditions.

- (1) Strap terminal A1 to A2 and B1 to B2 with short pieces of heavy gauge wire. Set RANGE switch to one of the higher ranges, set both dials to zero and Key switch to BALANCE INDUCTANCE.
- (2) Rock RESISTANCE dial clockwise and anti-clockwise about $\frac{1}{4}$ -turn of the fine adjustment knob. It will be found that at one end of the adjustment of the Detector Phase control the meter needle will move in the same direction as the movement of the RESISTANCE dial and at the other end of the adjustment it will move in the opposite direction to the dial. Somewhere between these extremes will be found a point at which minimum movement occurs. Set the preset control to this point.
- (3) Check that this adjustment has been properly made by turning both dials off zero and re-balancing in the normal manner, balancing resistance first. It should be possible to find balance by not more than 2 operations on each dial. If this is not possible repeat (1) and (2) under "Detector Phase Adjustment VR3".

Slidewire Range Control VR2

This control is provided to bring the effective resistance of the slide wire to exactly the required value. Its correct setting is obtained by connecting a standard resistor between the A1-B1 and A2-B2 terminals, making the Inductance Balance, setting the resistance balance dial to the exact value of the standard and adjusting VR2 and the Inductance Balance until the meter reads zero. Check that the zero

of the RESISTANCE dial has not altered. Should this be wrong it can be corrected by moving the dial on the spindle and rechecking as above.

Trimming Capacitors (C29-C36)

These components are for the leakage reactance of transformer T6. They are adjusted so that a truly non-inductive resistor is so indicated on each range of the instrument.

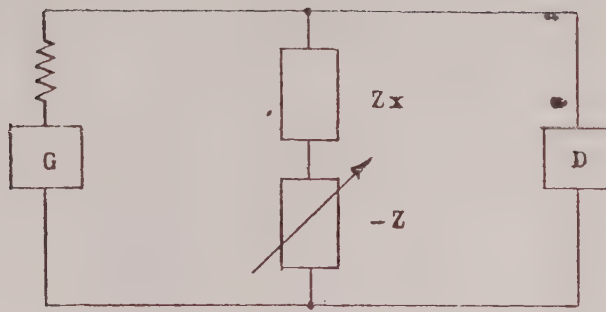


Fig. 1

1:1

1:1

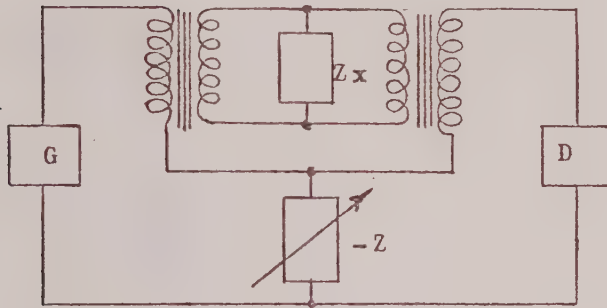


Fig. 2

1:m

n:1

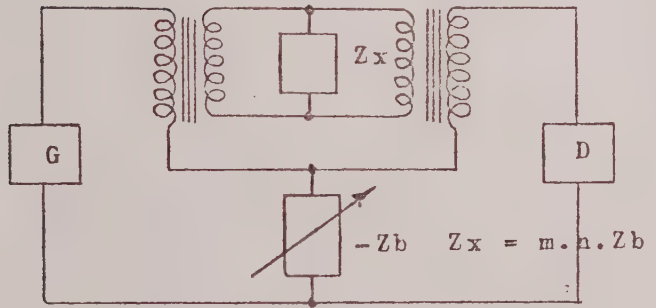


Fig. 3

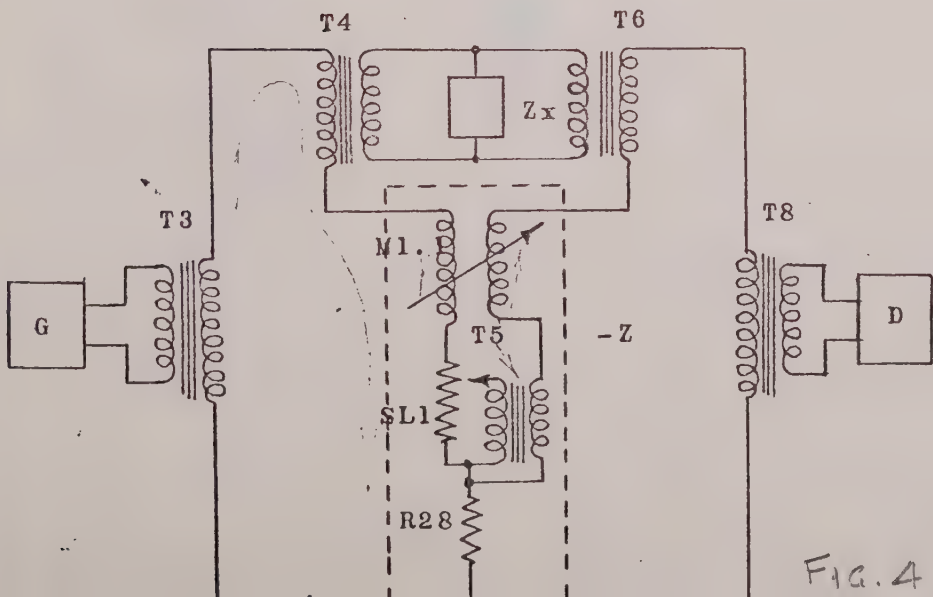


Fig. 4

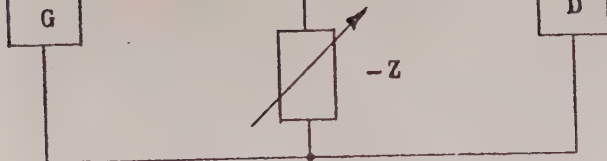


Fig. 1

1:1 1:1

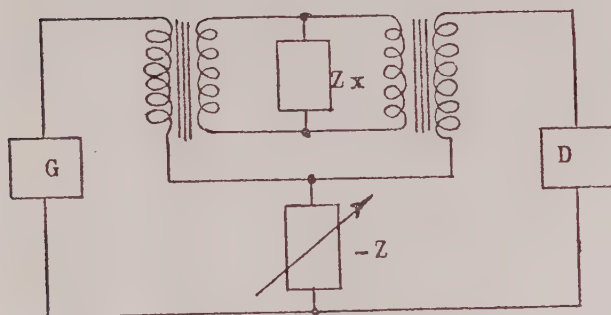


Fig. 2

1:m n:1

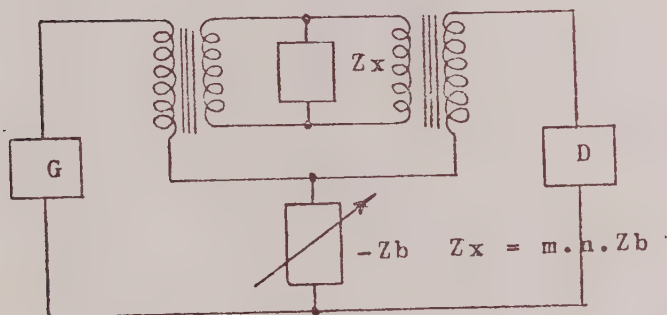


Fig. 3

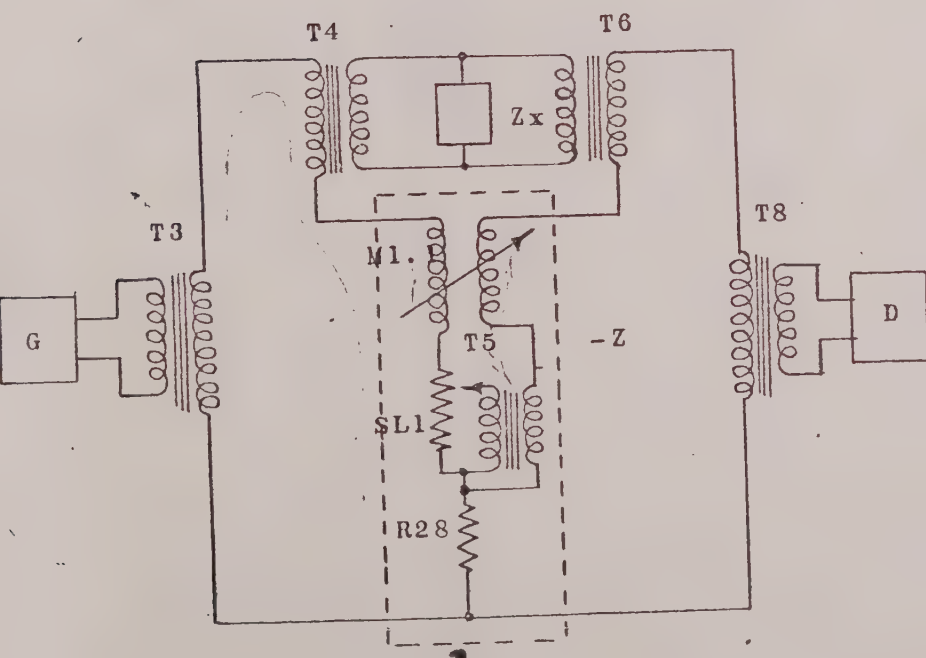
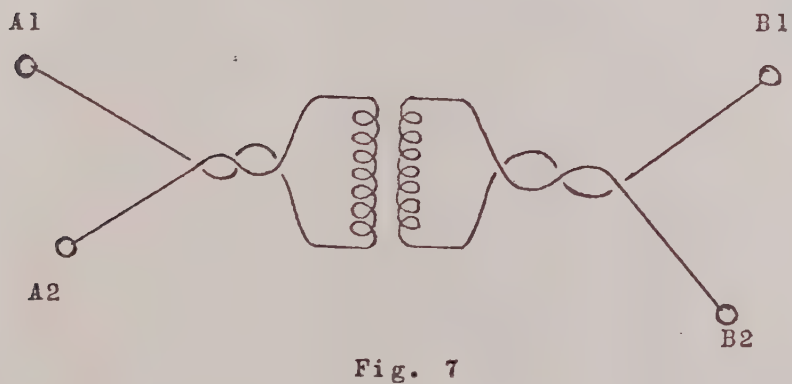
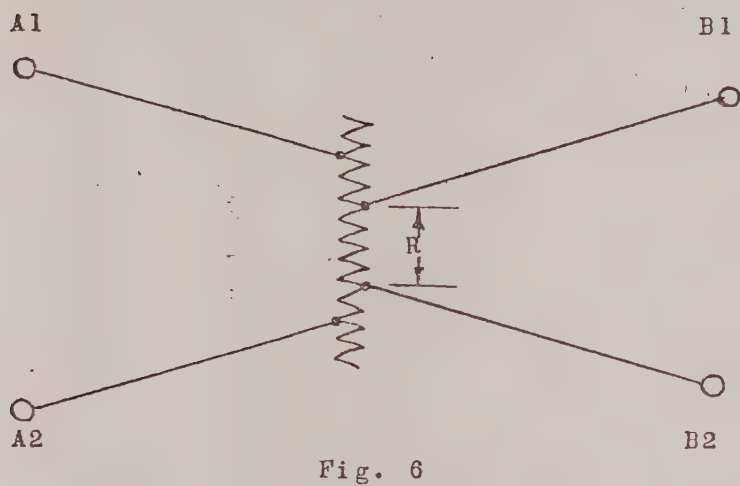
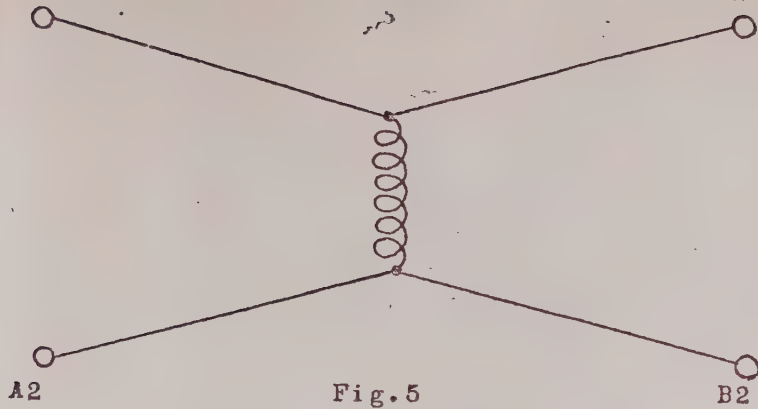
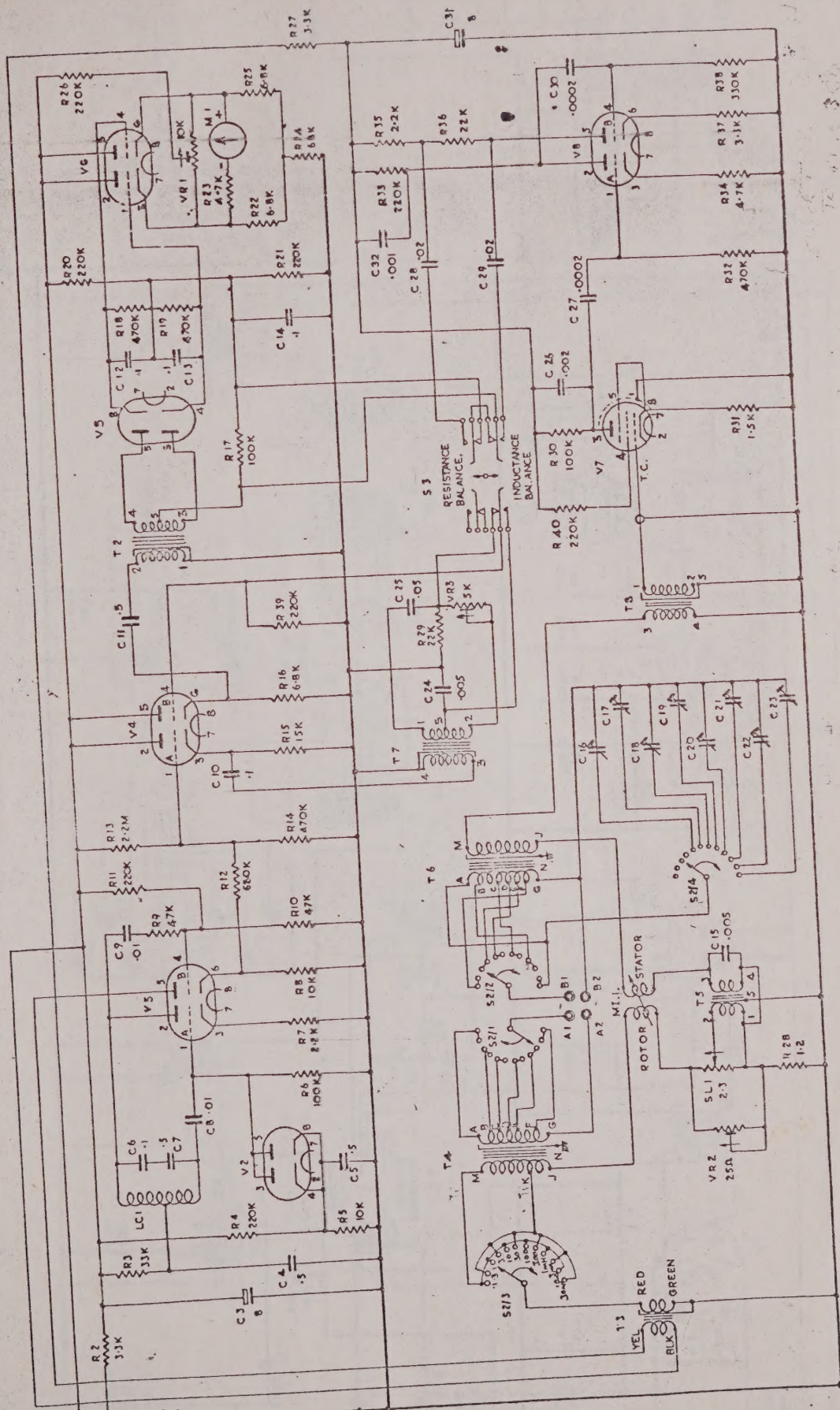


Fig. 4

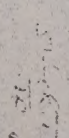




TO VALVE
RI 02
HEATERS

1949

00-



MP MASTER



MA23842